# FUZZY LOGIC BASED SELECTION OF RENEWABLE ENERGY SYSTEM WITH DEMAND SIDE MANAGEMENT FOR RURAL AREA

**Synopsis**

Submitted in the partial fulfilment for the requirement of

**Doctor of Philosophy**

in

**ELECTRICAL ENGINEERING**

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**1. MOTIVATION:** India is the 2nd most populated country in the world and renewable energies are abundant. The need of electricity is also very high in india. The energy sources which are clean,easily available and cannot be exhausted are known as renewable sources (solar, wind, hydro,biomass,ocean etc.).Renewable energy can overcome the energy crises and plays a very important role in growth of today's economies.Electtrification of rural areas located in the hills is a challenge faced by the local population.[1]

Many researchers have designed and developed renewable energy systems for different areas, but very few have defined the process of selecting suitable types of criteria and objectives. The problem arises due to the mismatch of simulated integrated renewable energy system (IRES) with the requirements needed during its on field implementation. Advancements in technology, supportive policies, increased investment, and infrastructure development are vital in enhancing their availability. Geographical variations and public awareness also shape their accessibility. By prioritizing these factors, societies can mitigate climate change impacts and transition towards a cleaner, and a more realistic model of the location. Hence ranking of criteria for objective and constraints selection are prerequisites for the development of IRES in the area.

This will lead us to formulate the problem very close to the reality. It will be followed by the optimization of the problem and selection of the system component size with and without demand side management. The variation of the load from low power consumption to high power consumption can be considered while simulating the system.

Electrification of remote rural areas is becoming a necessity, as it will generate additional local employment, improve health care and schooling facilities, resource utilization and better connectivity etc. Rural electrification is a path to realize these possibilities. It will also ensure that the households are connected and get a continuous, uninterrupted power, through the grid or off grid energy systems.

**Benefits of rural electrification:** Electrification is very important for any locality it can bring prosperity to the local population of that area.Some major Points are written below:

(i) Electrification of unelectrified sites

(ii) Grid connectivity is costly in hilly areas

(iii) Healthy society

(iv) Sustainable environment

(v) Improvement of education

(vi) Reduce the emigration

(vii) Poverty alleviation

(viii) Self sufficient and sustainable village

**2. NEED OF THE STUDY:** Electrification of rural areas at low cost and high reliability.Many researcher's have designed integrated renewable energy or Hybrid energy system for rural areas but they have not emphasized the selection of criteria.Dynamic variation of load and generation plays a significant role while operating a renewable energy system in real time.Designing such an IRES will help us to better realise the system and will maintain reliable power supply.

It will increase the Innovations in products, practices and policies in rural areas and also enhance the Capacity building and community empowerment.

## 3. INTRODUCTION

The demand for energy is increasing at an escalating pace and cannot be fulfilled entirely by conventional energy systems, due to their limited supplies. In addition they have a radical impact on the environment. The prevailing energy demand is heavily dependent on fossil fuels [2, 3] which are not only limited and inadequately distributed on the earth′s crust [4] but are also associated with serious environmental problems [5]. On the other hand electricity in cleanest form is generated by the renewable energy sources [6], which are readily available in nature and are in exhaustible.[7]

India became the world's 3rd largest producer and also 3rd largest consumer of electricity. The rapid increase in energy consumption in the present scenario is transforming the lives of people.[8]

The primary objective for deploying renewable energy in India is to advance economic development, improve energy security, improve access to energy, and mitigate climate change [9]. Sustainable development is possible by the use of sustainable energy and by ensuring access to affordable, reliable and sustainable energy for citizens. Strong Government support and the increasingly opportune economic situation have pushed India to be one of the top leaders in the world's most attractive renewable energy markets.In India the energy demand is increasing rapidly since the past decades, as energy is needed for the industrialization,agricultural purpose,commecial and residential loads.[10]

The undesirable affects and scarcity of the conventional fuels attracted Government of India to focus its goal on production of energy from renewable Energy sources.[11]

The introduction is followed by literature review,research gaps,objectives and Methodology.

**4. LITERATURE REVIEW:** Literature review comprises of evaluation criteria and MCDM methods used for the selection of these criteria.

## 4.1 EVALUATION CRITERIA OF VILLAGES

The role of renewable energy systems becomes essential for remotely located villages present in Hills, forests, islands etc. Implementation of electrified system in hilly areas has their own challenges. These criteria's can be categorized into four major domains namely Economical, Technological ,Socio-political, and Environmental.[12]The description of these majors groups are discussed below:

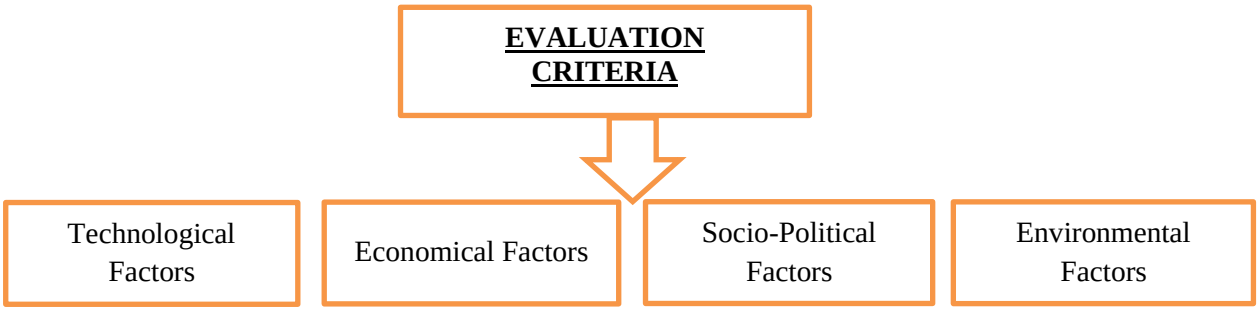



**Figure 1: EVALUATION CRITERIA**

**(A) TECHNOLOGICAL FACTORS:** Technology is ceaselessly advancing, with the development of ground-breaking technologies occurring every day.It covers new technology,production strategies and types of generator's,advancement of equipments,placements of generators ,selection of equipments, innovation,machine learning and artificial intelligences,data management practices,research and development etc.some of the commonly considered technological factors are listed below:

1. **Loss of power supply probability:** Renewable sources are random and intermittent in nature, , the determination of the reliability of the system becomes an important consideration. It is defined as the ratio of the total energy deficit to the total demand during the considered period.[13]

$$LPSP = \sum_{t=1}^{T} \boldsymbol{DE(t)} \,/\, \sum_{t=1}^{T} \boldsymbol{P_{load}}\ \textbf{(t)}\ldots\ldots\ldots\ldots\textbf{(1)}$$

2. **Equivalent loss factor:**Equivalent loss factor (ELF) is the ratio of effective load outage hours to

the total number of hours. It contains the information about both the number and magnitude of outages.[13]

$$\mathbf{ELF}=\frac{1}{H}\sum_{n=1}^{H}\frac{E(Q(H))}{D(H)}\text{.....(2)}$$

**3. Loss of load expected**:. Loss of load expected (LOLE) or expected energy not supplied is the energy that will not be supplied under the conditions when load exceeds generation.[13]

$$\mathbf{LOLE}=\sum_{h=1}^{H}E[LOL(h)] \quad \text{.....(3)}$$

**Where E[LOL]=**$\sum_{s\in S}T(S)\times f(S)$

**4. Total energy lost:** The total energy lost (TEL) due to extra power generation (PGS) from HES is minimized by imposing the regulation that such a quantity should not exceed a specific threshold over a defined analyzed period T.[13]

$$\mathbf{TEL}=\{\sum_{t=0}^{T}\big(E_{PGS}-LD(t)\big), if\ LD(t)<E_{PGS}(t)\text{.....(4)}$$

**5.Level of autonomy:** Level of autonomy (LA) is defined as one minus the ratio of the total number of hours in which loss of load (LOL) occurs and the total number of hours of operation.[14]

$$\mathbf{LA}=1-\frac{H_{LOL}}{H_{tot}}\text{.....(5)}$$

**6. Battery state of charge**:State of charge (SOC) in the batteries is related to the energy stored in a system.[14]

$$\mathbf{SOS(t+1)=SOC(t)}\sigma+I_{bat}\ (t)\Delta t\eta(I_{bat}(\mathrm{t}))\text{.....(6)}$$

**(B) ECONOMICAL FACTORS:** it covers all economic factors including tax rate,exchange rate,inflation,labor cost,demand and supply of material,wages,government activity or suport and recession.

1.. **Levelized cost of energy:**Levelized cost of energy (LCE) can be explained as the ratio of the total yearly cost of the system to the yearly electricity sent by the system.[15]

$$\mathbf{LCE}=\frac{TAC}{E_{tot}}\text{.....(7)}$$

**2. Capital recovery factor:** The capital recovery factor (CRF) can be interpreted as the amount of equal (or uniform) costs to be received for t years. [15]

$$\mathbf{CRF}=\frac{d(1+d)^t}{(1+d)^t-1}\text{.....(8)}$$

3. **Long term cost of the hybrid energy system**:Long term capital cost (Cn) of the system can be calculated as the sum of first installation cost, maintenance and operation cost and replacement cost.[15]

$$Cn=Ico[(1-\gamma)+m\frac{x^n-1}{x-1}+\frac{C_{oM_f}}{IC_o}\ y\frac{y^n\ -1}{y-1}+\varphi]\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

4. **Average generation cost of energy**:It is the average generation cost of energy (Cav) of all the devices included in the system design.[15]

$$Cav=\frac{[\left(r(1+r)^{n}+m\right)/((1+r)n^{\square})\ -1)]\sum_i Pi\ Ri}{(87.6)\sum_i RiKi}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

5. **Net present value**: Net present value (NPV) can be evaluated by adding the present discount values of the incomes while subtracting the discounted present costs through the useful lifetime of the system.[15]

$$NPV=\sum NPV_{sale\_i}+\sum NPV_{end\_i}-C_{investment}\ -\sum NPV_{r_i}-\sum NPV_{O\&M\_i}..(11)$$

6. **Annualized cost of system**:The annualized cost of system (ACS) is composed of the annualized capital cost, annualized maintenance cost (Camain) and the annualized replacement cost (Carep)[15]

$$ACS=C_{acap}+C_{amain}+C_{arep}\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(12)$$

**(C)SOCIO-POLITICAL FACTORS**; socio-political factors include security, poverty, national wealth, income inequality, social integration and political conflicts also include factors such as [6]

**1. Income:**It covers all kind of income of that area.[16]

**Per Capita Income = Total Income of Area / Total Population ……..…(13)**

**2. Education:** It plays very important role in growth of any organization.It can be calculated by the education cost formula[16]

$$E\hat{}\ it\ =\ e\ (\alpha Cit+\ \beta\bar{Q}\ t+\ \gamma\bar{Ft}\ )\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(14)$$

**3. Employment:** In employment we calculate the total no of job offered by organization.[16]

**Employment rate = (number of people who are employed / total labor force) x**

**100……..(15)**

**4. Community safety:** This object seeks to enhance the the safety of community.[17]

**5. Social support:**It requires all kind of support of people.[17]

**6. Social acceptance:**Social acceptability (SA) is included as social performance evaluation criteria in order to take into consideration the social resistance to the installation of HES.[17]

**7. Portfolio risk:**This objective seeks to minimize the exposure to fuel price instability for carrying out socio-political decisions.[18]

**8.Compatibility with the national energy policy objective:** The National Energy Policy (NEP) aims to chart the way forward to meet the. Government's recent bold announcements in the energy domain.[18]

**9. Labor impact:** The impact of immigration overall on the economy is likely to be small and for any negative effects to dissipate over the longer term as the economy adjusts to a larger labor supply.[18]

**(D)ENVIRONMENT FACTORS:** Environmental Factors cover the weather pattern,quality of essential chemical constituents available in the local environment.some commonly used environmental factors are:

**1. Osmolarity**:Osmolarity is a process of measurement of solute concentration.[19]

**Osmolarity=(2×sodium)+(glucose/18) + (BUN/2.8)+(ethanol/4.6)…(16)**

**2.PH:** It is a measurement of the level of acid or alkali in a substance.[19]

$$pH = -log[H_3O^+] \text{……..(17)}$$

**3.Temperature:** Temperature is a physical quantity that expresses quantitatively the perceptions of hotness and coldness of that area.[19]

$$\Delta T = Q/mc \text{……..(18)}$$

**4.Humidity:** Humidity is the amount of water vapor in the air of that area. [19]

**R.H. = vapour pressure/saturation vapour pressure × 100……(19)**

**RH = 100 × {exp[17.625 × Dp/(243.04 + Dp)]/exp[17.625 × T/(243.04 + T)]}**

**5.Oxygen Concentration:** Oxygen concentration (cO2) is calculated by determining hemoglobin concentration (Hb) and oxygen saturation (sO2).[19]

**co2=(Hb×so2×1.36)+(po2×0.0032)…….(20)**

**6.Pressure:** Pressure is defined as **the physical force exerted on an object**. The force applied is perpendicular to the surface of objects per unit area.[19]

**P = F/A……..(21)**

7.**Pollutant emission**:The criterion measures the equivalent emissions of $CO_2$, air emissions which are the results of the combustion process, liquid wastes which are related to secondary products by fumes treatment or with process water, and solid wastes.[20]

**Mi. = Vmix * Qi * kH * Ci * 10-6 / Ds. Mi. ……(22)**

**8.Land requirement:** Land requirement is one of the most critical factors for energy investment.[20]

**4.2 SELECTION OF CRITERIA USING MULTI CRITERIA DECISION MAKING METHODS:** Multicriteria Decision Making (MCDM) is a process that involves evaluating and prioritizing multiple conflicting criteria in decision-making situations.[21] It integrates various methodologies to assess options systematically, aiding in selecting the optimal choice by considering diverse factors and preferences.[22]MCDM is essential in complex, real-world decision scenarios.The MCDM technique are listed in table 1:

**1.Adaptive Neuro-Fuzzy Inference System (ANFIS)**

**2.Analytical Hierarchy Process (AHP)**

**3.Simple Additive Weighting (SAW)**

**4. Weighted-Product (WP)**

**5. Multi-Factor Evaluation Process (MFEP)**

**6. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)**

**Table 1: Multi criteria decision making methods**

| Method | Approach | Input | Application(Output) | Conclution |
|---|---|---|---|---|
| **1.Adaptive Neuro-Fuzzy Inference System (ANFIS) [23]** | Artificial Intelligence, Artificial Neural Network,Fuzzy inference system. | ANFIS requires a suitable dataset for training and testing to adjust its membership functions in order to provide effective performance in demand side management.[23] | ANFIS integrates neural networks and Fuzzy Logic principles, has the ability to take advantage of both within a single framework. | ANFIS technique has been widely applied successfully for control models because it presents a proper combination of the neural network and fuzzy logic. |
| **2.Analytical Hierarchy Process (AHP)** [24] | Decision-making techniques. | AHP requires weighted criteria scores that combine all of the ranking **data** of any problem.[24] | The AHP is most useful when finding decisions to complex problems with high stakes. | AHP helps decision makers find one that best suits their values and their understanding of the problem. |
| **3.Simple Additive Weighting (SAW) [24]** | Simple Additive Weighting Decision-making techniques. | Decision support systems can be used in the processing of **data** to facilitate decision-making process. | selection problem in a multi-process decision-making system. | The SAW method was chosen because of this method determine the weight value for each attribute, then proceed with a selection process to choose the best alternative from a number of existing alternatives |
| **4. Weighted-Product (WP) [24]** | Weighted Product method. | weighted criteria data in decision making method. | Weighted Product Method is a multi-criterion decision-making method in which there will be multiple alternatives and we have to determine the best alternative based on multiple criteria. | Weighted Product method, instead of calculating sub-scores by multiplying performance scores times attribute importance, performance scores are raised to the power of the attribute importance weight |
| **5. Multi-Factor Evaluation Process (MFEP) [24]** | Multi-Factor Evaluation model. | MFEP (Multi Factor Evaluation Process) method., by determining and giving subjective / intuitive assessments. | It is a decision making method that uses a collective approach or in other words, together or a combination of decision making processes | The feasibility evaluation of renewable energy power plants from multi criteria is necessary to save energy, protect environment and develop technology. |

| | | | | |
|---|---|---|---|---|
| **6. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [25]** | **TOPSIS** algorithm follows the distance principle that leads to abnormality in ranking results of parameters. | TOPSIS,Technique for order preference by similarity to ideal solutions. Articulate an initial alternative/criteria decision matrix having a dimension of a×c, where a is the number of alternatives and c is the number of performance indictors/criteria. | This technique is only can be applied for the numerical dataset where the importance weights of the criterion known or defined based on the experts opinion numerically. | The preferred alternative is the one with the most close to the positive ideal solution and the further to the negative ideal solution. |

**Table 2: Advantages and Disadvantages of MCDM Methods [26][27]**

| METHOD | Advantages | Disadvantages |
|---|---|---|
| **1.Adaptive Neuro-Fuzzy Inference System (ANFIS)** | Captures nonlinearity of a process.<br>Automatic adaptation capability.<br>Rapid learning capacity.<br>High generalization capability.<br>High flexibility allows many variants. | Selecting type and number of membership functions.<br>Location of a membership function.<br>Curse of dimensionality.<br>Interpretability-accuracy trade-off.<br>High computational cost. |
| **2.Analytical Hierarchy Process (AHP)** | Allows the DMS to structure the decision making problem into a hierarchy tree<br>facilitates understanding of the problem<br>Presence high time consumption because of the number of pair-wise comparisons and requires mathematical calculations that increase as the number of attributes and alternatives increase or change<br>Presents higher time consumption because of the number of pair-wise comparisons and requires mathematical calculation that increase as the number of attributes and alternatives increase or change. | Scoring and ranking in AHP depends on the alternatives consider for evaluation.<br>The removal or addition of alternatives may change the final ranking( rank reversal problem). |
| **3.Simple Additive Weighting (SAW)** | Considers all criteria's alternatives Offers simple calculation and makes decisions intuitivly. | Does not commonly discover the real situation.<br>All criteria values must be positive and maximum |

| | | |
|---|---|---|
| **4. Weighted-Product (WP)** | It permits decision-makers to relegate weights subjectively based on their inclinations or utilize more organized strategies for weight assurance, such as AHP | Criteria should be independent of each other.<br>Lack of theoretical basis for weights |
| **5. Multi-Factor Evaluation Process (MFEP)** | It takes the uncertainties and decision makers' preference into consideration. | It needs a lot of input, and preferences need to be precise. |
| **6. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)** | TOPSIS apply to discreet alternative challenges and they are the most significant approaches to solve real world problems.<br>TOPSIS have the ability to immediately recognise the proper alternative.<br>TOPSIS decreases the pair wise comparisons required and the capacity limitations may not significantly control the process.<br>TOPSIS Usable for situations with many alternatives and attributes.<br>TOPSIS are appropriate to utilize when quantitative or objective data are offered.<br>TOPSIS are based on an aggregating function representing closeness to the idea which originated in the compromise programming method | TOPSIS lack to elicitation and check the consistency of judgments.<br>TOPSIS does not consider the relative importance of distances. |

**4.3 SELECTED METHOD (TOPSIS)**:TOPSIS, first introduced by Yoon and Hwang (1981), is a technique to assess the performance of alternatives through the similarity with an ideal solution. It is known as one of the most important MCDM methods. This method uses precise numbers in the rating of alternatives, causing less dealing with uncertainties (Chung et al. 2017; Orojloo et al. 2018). According to this technique, the best alternative would be the one that is closest to the positive-ideal solution and farthest from the negative-ideal solution.[28]

**4.4 FUZZY LOGIC-BASED DEMAND-SIDE ENERGY MANAGEMENT SYSTEM** An optimal energy management system is proposed for a hybrid PV-Battery storage system. Fuzzy logic is used to control the battery storage system and grid-connected inverter, and its associated control is used to control power flow in the grid-tie line. The control strategy is designed, so that power flow from the grid happens only during contingency and normal operation; the battery storage system handles any power fluctuation and ensures optimal utilization of resources. [29]

**Table3: Demand-side management using AI Techniques**

| YEAR | RESEARCH TOPIC | Approach | Conclusion | Outcomes obtain | Research GAP |
|---|---|---|---|---|---|
| 2016 | Fuzzy Logic-Based Energy Management System Design for Residential Grid-Connected Microgrids[30] | Fuzzy Logic-Based Energy Management System Design for Residential Grid-Connected Microgrids | A FLC-based design of an EMS for smoothing the grid power profile of a grid-connected residential microgrid with renewable generators and battery storage capability. | SOC can compensate the MG net power fluctuations (thus smoothing the grid power profile) while keeping the SOC within secure limits. | The system assumes that neither the renewable generation nor the load demand is controllable. |
| 2018 | Development of a Fuzzy-Logic-Based Energy Management System for a Multi-Port Multi-Operation Mode Residential Smart Micro-grid[31] | Fuzzy logic control | fuzzy logic-based energy management unit (EMU) for residential micro-grid applications has been presented. The EMU contained a short-term and a long-term control unit. | The energy distribution and energy cost analysis provided for each energy management scenario, showed the benefits of using proposed EMU for both consumer and utility grid. | To validate the operation of the proposed EMU, a prototype of the system has been developed and experimental tests have been conducted. |
| 2018 | Multiobjective Robust Scheduling for Smart Distribution Grids: Considering Renewable Energy and Demand Response Uncertainty[32] | Robust optimization theory, Nondominated set genetic algorithm-II | The robust optimization model can address the uncertainty problems of both supply and demand sides, which are unsolvable in the traditional deterministic model, and the optimization scheme can satisfy all extreme scenarios. Uncertainty of demand/load increases, to ensure the reliability of the optimization results. | System must balance operating costs with renewable energy utilization. | Uncertainties of generation in renewable energy and multitype DR resources are described in the form of robust intervals on multiple time scales. |

| | | | | | |
|---|---|---|---|---|---|
| 2020 | A Novel Predictive Fuzzy Logic-Based Energy Management System for Grid-Connected and Off-Grid Operation of Residential Smart Microgrids[33] | Energy management, fuzzy logic control, predictive control. | The efficiency performance of the microgrid components and the energy cost is included in the management process., A fuzzy controller is used to determine the operation mode of the system according to the real-time data. | Proposed energy management technique on the reduction of consumer's electricity bill was approved. | Fuzzy controller is used to determine the operation mode of the system according to the real-time data. |
| 2021 | An Energy Management System Design Using Fuzzy Logic Control: Smoothing the Grid Power Profile of a Residential Electro-Thermal Microgrid[34] | Fuzzy Logic Control, power smoothing, microgrid. | EMS has been designed based on FLC to smooth the power profile exchanged with the grid and limiting the injection of RES into the mains. | It reduce the impact on the grid power when renewable energy sources are incorporated to pre-existing grid-connected household appliances. | Neither renewable generation nor the electrical and thermal load demands are controllable. |
| 2021 | Game-Theoretic Demand Side Management of Thermostatically Controlled Loads for Smoothing Tie-line Power of Microgrids[35] | Game-theoretic DSM | This paper proposes a game-theoretic DSM to smooth the tieline power for MGs based on a power consumption game among TCLs. | Dynamic-programmingachieves fast response and high accuracy in the power consumption game. better performance in power smoothing and cost-saving. | By choosing appropriate parameters and carefully designing an artificial cost function. |
| 2022 | A Self-Organized Method for a Hierarchical Fuzzy Logic System Based on a Fuzzy Autoencoder[36] . | fuzzy partition algorithm | The hierarchical self-organized fuzzy system still performs better in terms of regression accuracy indicators than the self-organized fuzzy system | Hierarchical fuzzy system reduces the total number of rules and the complexity. | Experimental results illustrate that the hierarchical self-organized fuzzy system still performs better in terms of regression accuracy indicators than the self-organized fuzzy system. |

| | | | | | |
|---|---|---|---|---|---|
| 2023 | Multiobjective Optimization Design of Interpretable Evolutionary Fuzzy Systems With Type Self-Organizing Learning of Fuzzy Sets[37] | Self-generated interpretable fuzzy logic system (FLS). | The simulation results achieve a good trade-off between performance and interpretability | Self-generated FLSs achieve a good balance between interpretability and performance. | No training data are collected in advance. |

**5.RESEARCH GAP'S IDENTIFIED:** The challenges associated with rural electrification comprises of social, political, economic and technical barriers etc.According to the study of the literature following research gaps can be listed:

(i) Ranking of Criteria from different available parameters for village Electrification.

(ii) Demand side management with dynamic load fluctuation.

(iii) Reluctance of power generation, distribution and transmission companies to connect these localities due to lack of return on investment.

(iv) The change in the demography of the region can increase burden in the system and the subsequent changes must be incorporated in detail before the implementation of the project otherwise it may become infeasible.

**6.OBJECTIVES OF STUDY:**

Obj. 1. Ranking of Criteria from different available parameters for village Electrification.

Obj. 2. To formulate the objective function and selection of constraints based on ranking of multiple criteria in the design of IRES for the case study.

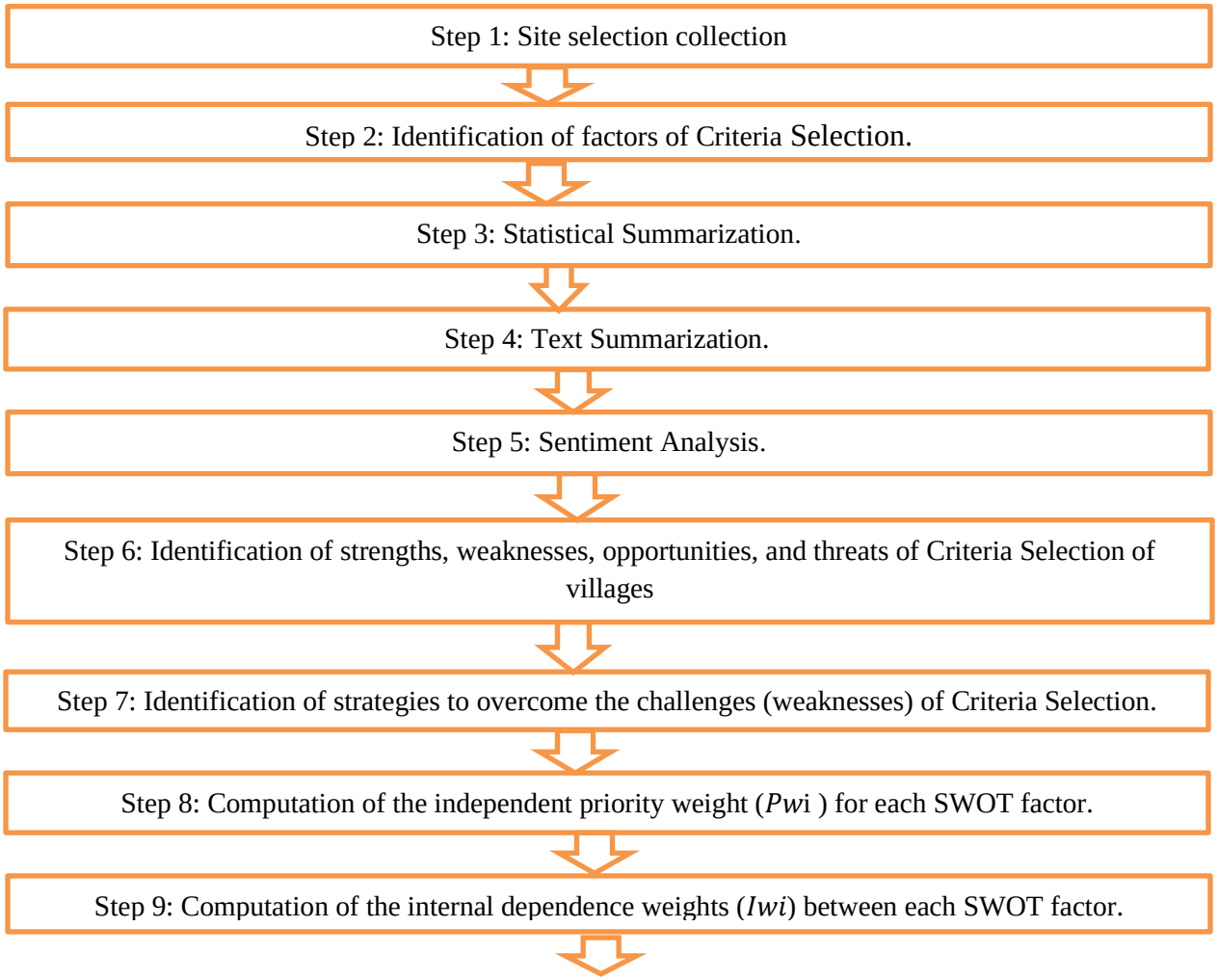
Obj. 3. Optimization of the size of system components with and without demand side management for the designed objective function and constraints.

Obj. 4. Determining shortest path for laying and maintenance of power distribution network for the study area.

**Obj. 5.** Dynamic variation in the power generated from renewable energy systems and requirement of load to make the system more practicable.

## 7.METHODOLOGY:

**7.1 "Flow chart and Methodology For MCDM to achieve first Objective":** SWOT Analysis is combined with ANP (Analytical Network Process) and TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) methods to design the strategies for overcoming various challenges of criteria selection of villages. The SWOT analysis is performed to identify the strengths, weaknesses, opportunities, and threats of criteria selection of villages for renewable energy system. ANP and TOPSIS are utilized to prioritize the strengths, weaknesses, opportunities, and threats, and then determine the improvement strategies.[38]


Step 1: Site selection collection
Step 2: Identification of factors of Criteria Selection.
Step 3: Statistical Summarization.
Step 4: Text Summarization.
Step 5: Sentiment Analysis.
Step 6: Identification of strengths, weaknesses, opportunities, and threats of Criteria Selection of villages
Step 7: Identification of strategies to overcome the challenges (weaknesses) of Criteria Selection.
Step 8: Computation of the independent priority weight (Pwi ) for each SWOT factor.
Step 9: Computation of the internal dependence weights (Iwi) between each SWOT factor.

Step 10: Computation of the interdependent priority weight ($Dwi$) for each SWOT factor using equation $Dwi = Pwi \times Iwi$

Step 11: Calculating the global priorities $Gi$ of the SWOT sub-factors using equation: $Gi = Li \times Dwi$ Where $Li$ is local priority weights of the SWOT sub-factors

Step 12: Establishing an aggregated decision matrix by making a pairwise comparison of alternatives with respect to strength, weakness, opportunities, and threats respectively to get the decision weights

Step 13: Calculation of the normalized decision matrix using equation : $r_{ij} = \frac{fij}{\sqrt{\sum fij^2}}$ Where, $rij$ are the normalized elements of the matrix.

Step 14: Determination of the Positive Ideal Solution (R+ ) and the Negative Ideal Solution (R- )

$$R+ = \{maxirij | j \in J, i = 1,2, \dots, n\}$$

$$R- = \{minirij | j \in J, i = 1,2, \dots, n\}$$

Step 15: Calculating the weighted Euclidean distances for each strategy using equations:

$$Di+ = \sqrt{\text{wij(rij} - \text{Rj}+)^2}$$

$$Di- = \sqrt{\text{wij(rij} - \text{Rj}-)^2}$$

Step 16: Calculation of the relative closeness coefficient using equation :

$$Ci = \frac{\text{Di}+}{\text{Di}+ - \text{Di}-}$$

**Figure 2: Flow chart of TOPSIS method**

**7.2 "Flow chart and Methodology for Development of Integrated renewable energy system to achieve second, third objective":** Development of Renewable energy system is important for empowerment of the people living in the distant regions through the supply of uninterrupted electricity.[39]Hence, a methodology is developed to fulfill this objective.

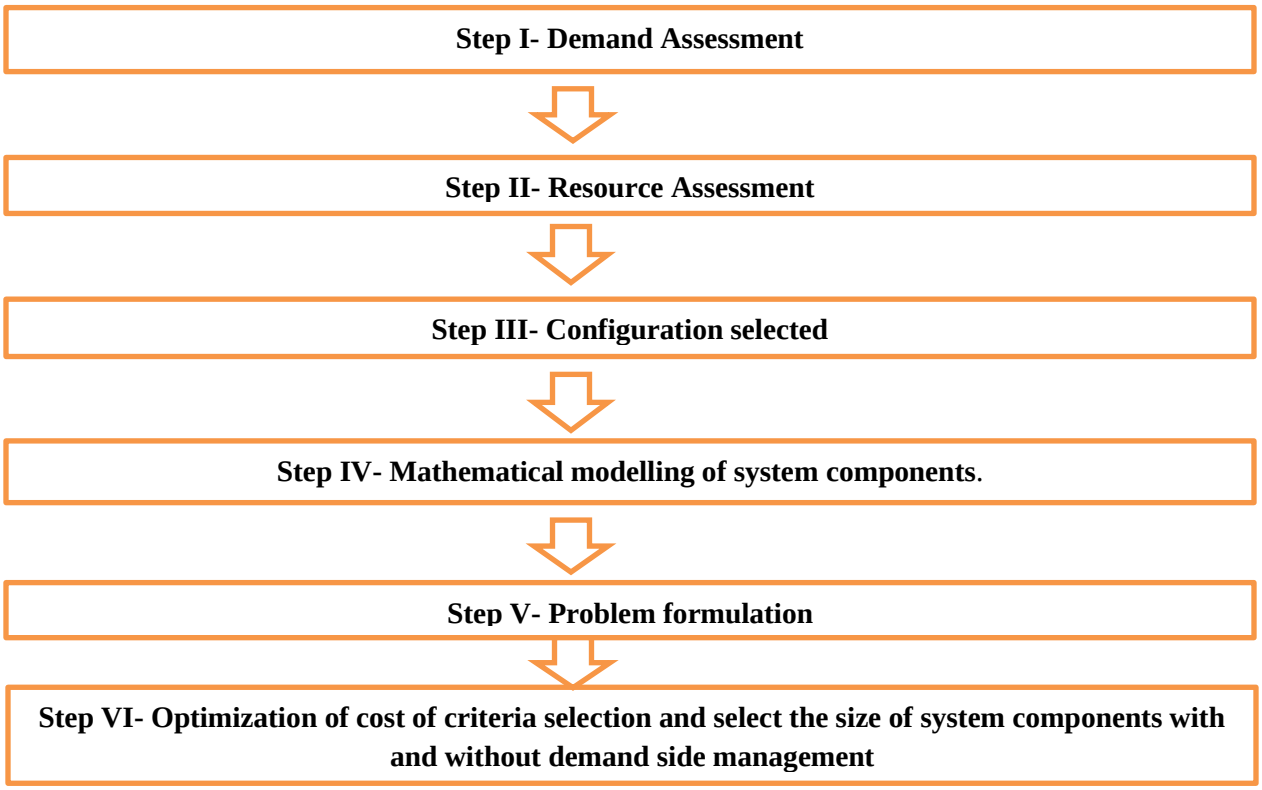

Step I- Demand Assessment
Step II- Resource Assessment
Step III- Configuration selected
Step IV- Mathematical modelling of system components.
Step V- Problem formulation
Step VI- Optimization of cost of criteria selection and select the size of system components with and without demand side management

**Figure 3: Flow chart of IRES**

**Step I- Demand Assessment**: Domestic loads (i.e. household), societal loads (i.e. schools, panchayat office etc.), commercial loads (i.e. shops) and industrial loads (i.e. saw mills and flour mills) are the major forms of loads found in the region.

**Step II- Resource Assessment** Resource assessment includes determining the locally available resources to fulfill the demand.

**Step III- Configuration selected** The resource availability shows that the renewable energy potential of the area is not sufficient to support an only renewable energy system.

**Step IV- Mathematical modelling of system components**: Mathematical modelling of components constituting IRES is developed, which reflects its performance at normal operating conditions.

**Step V- Problem formulation**: The formulation of problem includes objective function and constraints determination. The objective function and constraints reflects size of system components.

**Step VI- Optimization of cost of critera selection and select the size of system components with and without demand side management**

**7.3 Methodology for achieving Fourth objective:** Location is mountaneous and Deploying renewable energy systems in mountainous terrain presents challenges such as limited accessibility for construction and maintenance, harsh weather conditions, and geological constraints. Transmission lines in rugged landscapes can be costly and environmentally sensitive. Shortest path for laying and maintenance of power distribution network will reduce the overall network , cost and power loss.[40]

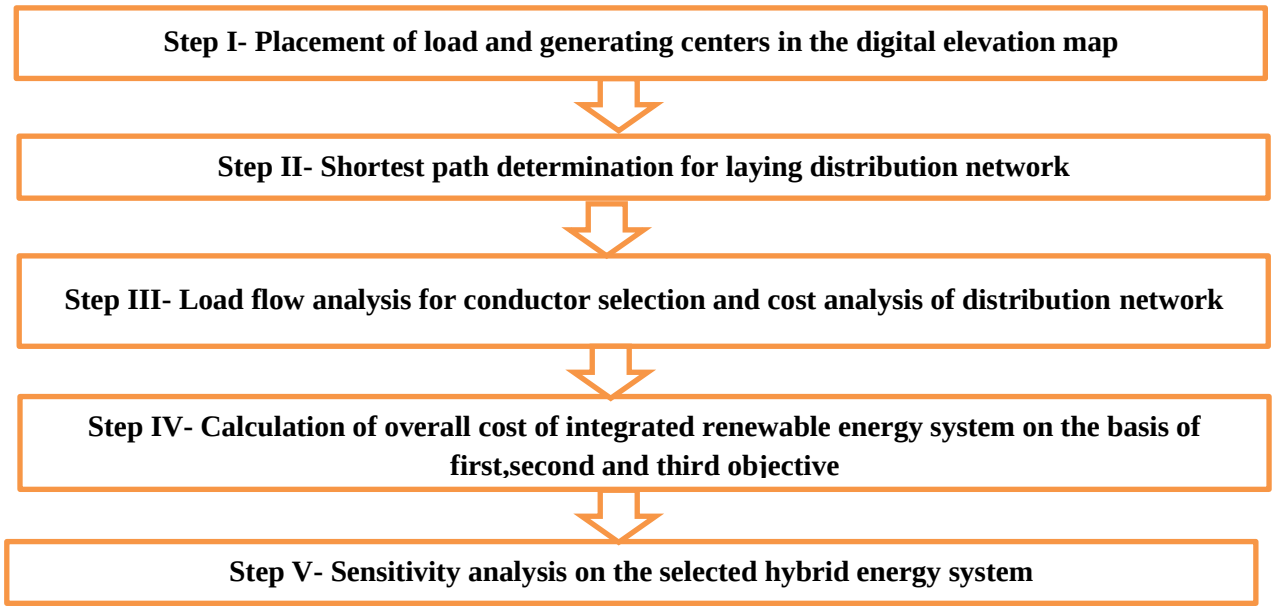

Step I- Placement of load and generating centers in the digital elevation map
Step II- Shortest path determination for laying distribution network
Step III- Load flow analysis for conductor selection and cost analysis of distribution network
Step IV- Calculation of overall cost of integrated renewable energy system on the basis of first,second and third objective
Step V- Sensitivity analysis on the selected hybrid energy system

**Figure 4: Flow chart for shortest path**

**Step I- Placement of load and generating centers in the digital elevation map** The obtained size of generators from step VI are placed in the digital elevation map according to the location of the villages and generating stations provided in the data.

**Step II- Shortest path determination for laying distribution network** The shortest path in each section (between two generating/load centers) is optimized and intermediate nodes are determined, through which distribution network will pass. By adding each sectional distance the overall distance is calculated.

**Step III- Load flow analysis for conductor selection and cost analysis of distribution network** Load flow analysis is conducted to determine power loss and voltage drop associated with each type of conductor. According to the selected conductor, its cost in drawing distribution network is determined.

**Step IV- Calculation of overall cost of integrated renewable energy system on the basis of first,second and third objective**: The overall cost of energy comprises of net present cost of integrated

renewable energy system.

**Step V- Sensitivity analysis on the selected hybrid energy system:** Finally the sensitivity analysis is carried out on the integrated renewable energy system. It signifies the variation of resource availability and demand, which affects the cost of energy of overall integrated renewable energy system.

## 7.4 CASE STUDY:

**(a)Rural Site Identification and its description :** Gara Parli ,Shakti and Maror villages of Sainj block of Kullu,Himanchal Pradesh,India, has been selected for the development of integrated renewable energy system.

**(b)Assessment of loads and load distribution:** The load and potential of natural resources will evaluated as Per the data collected.The energy demand will consider domestic loads,community load,commercial load and low power industrial load(saw mill or paddy huller).

**(c)Types of Sources available in the area, grid presence:** It covers all type of renewable resources present near the particular villages.

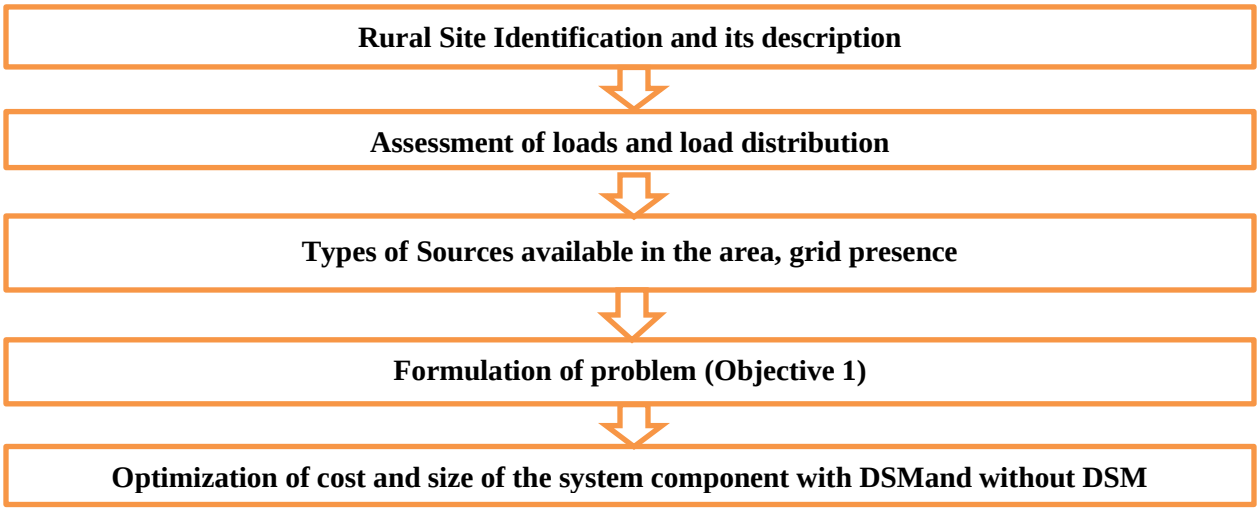

Rural Site Identification and its description
Assessment of loads and load distribution
Types of Sources available in the area, grid presence
Formulation of problem (Objective 1)
Optimization of cost and size of the system component with DSMand without DSM

**Figure 5: Flow chart for case study**

## 8. PROFILE OF THE STUDY AREA

**8.1 State of Himanchal Pradesh**: It is a state in the northern part of India. Situated in the Western Himalayas, it is one of the thirteen mountain states and is characterized by an extreme landscape featuring several peaks and extensive river systems. Himachal Pradesh is the northernmost state of India

and shares borders with the union territories of Jammu and Kashmir and Ladakh to the north, and the states of Punjab to the west, Haryana to the southwest, Uttarakhand to the southeast and a very narrow border with Uttar Pradesh to the south. The state also shares an international border to the east with the Tibet Autonomous Region in China. Himachal Pradesh is also known as *Dev Bhoomi*, meaning 'Land of Gods [41] and *Veer Bhoomi* which means 'Land of the Brave[41] The villages are selected on the basis of forest cover.

## 8.2TARGATED VILLAGES FOR SELECTION OF RENEWABLE ENERGY SYSTEM WITH DEMAND SIDE MANAGEMENT

**Gara Parli**

Block / Tehsil → Sainj

District → Kullu

State → Himachal Pradesh

**Figure 6: Geographical location of the study area**
**(Source: https://maps.app.goo.gl/MMHxZxbQGnsy6VoR7)**

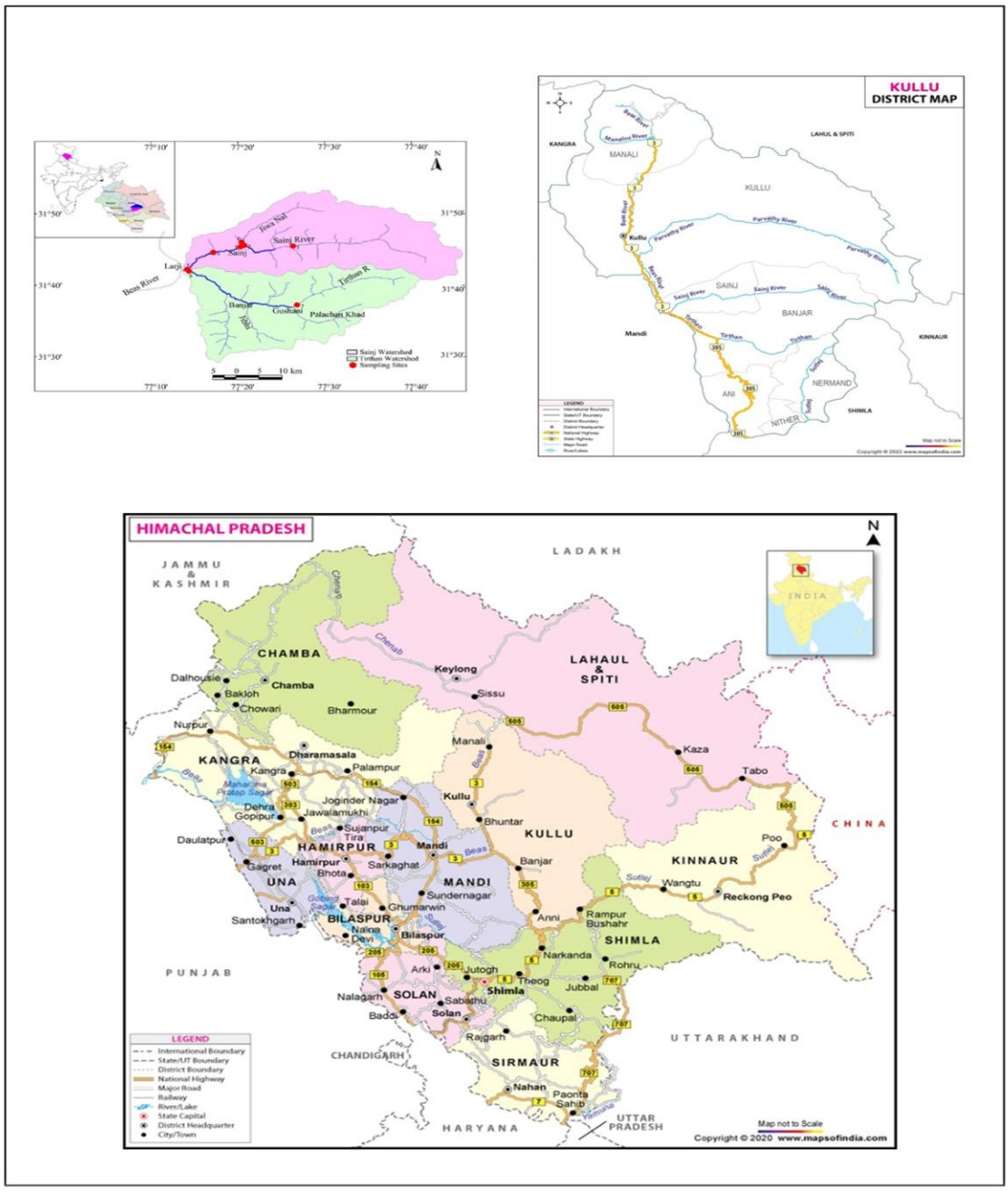



**Figure 7: Geographical location of the study area**
**(Source: https://maps.app.goo.gl/MMHxZxbQGnsy6VoR7)**

## 8.3 About Gara Parli

According to Census 2011 information the location code or village code of Gara Parli village is 012908. Gara Parli village is located in Sainj tehsil of Kullu district in Himachal Pradesh, India. It is situated 55km away from district headquarter Sainj. Sainj is the sub-district headquarter of Gara Parli village. As

per 2009 stats, Gadaparli is the gram panchayat of Gara Parli village.

The total geographical area of village is 218 hectares. Gara Parli has a total population of 1,025 peoples, out of which male population is 514 while female population is 511. Literacy rate of gara parli village is 57.46% out of which 63.81% males and 51.08% females are literate. There are about 207 houses in gara parli village. Pincode of gara parli village locality is 175134.Banjar is nearest town to gara parli village for all major economic activities.

### 8.3.1 Population of Gara Parli [41]

**Table 4: Gara Parli - Village Overview [41]**

| **Gara Parli - Village Overview** | |
|---|---|
| Gram Panchayat : | Gadaparli |
| Block / Tehsil : | Sainj |
| District : | Kullu |
| State : | Himachal Pradesh |
| Pincode : | 175134 |
| Area : | 218 hectares |
| Population : | 1,025 |
| Households : | 207 |
| Nearest Town : | Banjar |

## 8.4Description of selected Forest villages:Shakti and Maror village in Kullu district Manali block kulaura

Shakti, Maror and Shugad are great Himalaya National park in Kullu district are being forced to live without power,road connectivity,education and health facilities both are remotest village.Shakti is 17 km and Maror 24 km from the road at nihrani in Banjar.The 17 km track from Niharani to Shakti passes through a dense forest along the Sainj river.

Shakti village of gadaparli panchayat in Banjar subdivision is one of the most remote villages of

Himachal Pradesh and can be approached only after a 20 km steep trek.However,not one to give easily,Shari has sent a message to officials through villages that the locals wanted only two things to lead a more advanced lifestyle –"Electricity and Road connectivity.Suffering from lack of basic facilities since decades, the residents of Shakti-Maror and Shugad villages of Banjar subdivision in Kullu district have urged the state government to provide these at the earliest.

The location of these villages — vicinity of the Great Himalayan National Park (GHNP), Kullu, — is a hindrance in carrying out any development works.The villages do not have power supply, telecommunication facility and road connectivity since the Independence. They told The Tribune that six months ago, the HP State Electricity Board had sent over 200 electric poles to the villages, which raised their hopes of getting electricity supply. However, the poles are still lying there and no nothing has been done to install them. The villagers said there were reports an NOC was awaited for putting up power lines in the area.[41]"Villagers have to trek for 35 km to reach a road, which is a daunting task for senior citizens, children and patients.Similarly, lack of communication facility was a big hindrance.The villagers said the state government should take up the matter with the GHNP authority effectively so that a power line could be installed in the region.

The Great Himalayan National Park (GHNP) is a hindrance in carrying out development works in Shakti, Maror and Shugad villages in Kullu district. The way to these remote villages passes through the GHNP area in Sainj valley. The GHNP area is covered with forest trees like deodars. To provide road connectivity and install power lines, forest trees will be required to be pruned, getting approval for which from the GHNP is tough. Therefore, carrying out any development activity in these villages is proving difficult.

**Table 5: Combined description of Selected villages**

| Village | Location | | Population | No of household | Elevation |
|---|---|---|---|---|---|
| | Latitude | Longitude | | | |
| Gara parli | 31.957851 | 77.10945 | 1025 | 207 | 2065 meters |

| | | | | | |
|---|---|---|---|---|---|
| Shakti | 31.854328 | 77.10945 | 400 | 95 | 1,789 meters |
| Maror | 31.864431 | 77.10945 | 375 | 90 | 1,788 meters |

Hence our proposed work will include an optimal design of IRES in the area which will assist the villages for better livelihood in the region and ensure the employment in their doorsteps.

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